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(54) **BATTERY CAPACITY MONITOR**

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This patent is subject to a terminal dis-
claimer.

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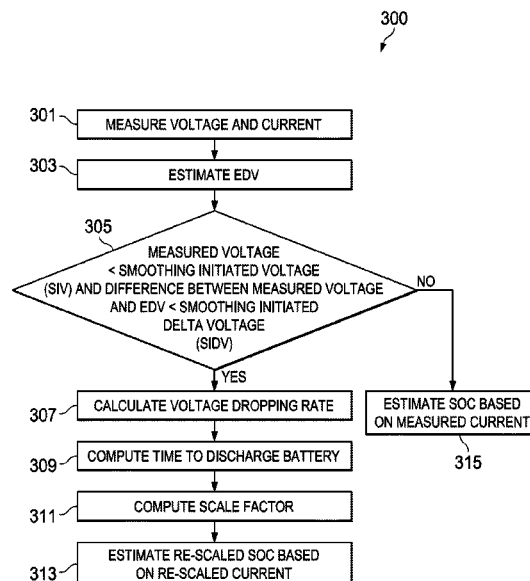
(57) **ABSTRACT**

A method for dynamically monitoring a capacity of a battery
includes estimating a first voltage threshold of the battery
that is being discharged, wherein the first voltage threshold
corresponds to a low capacity of the battery, and measuring
a present voltage and a present current of the discharging
battery. The method further includes re-scaling the present
current based on the estimated first voltage threshold and the
measured present voltage of the discharging battery, and
calculating, based on re-scaling the measured present cur-
rent, the battery's capacity before the present voltage level
decreases below the first voltage threshold.

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27 Claims, 2 Drawing Sheets



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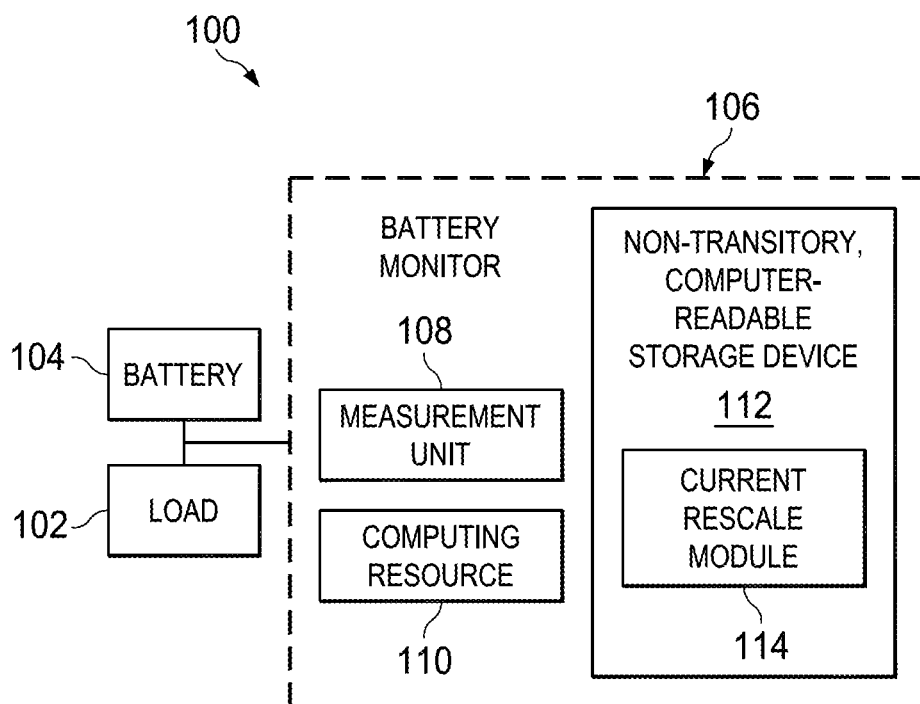


FIG. 1

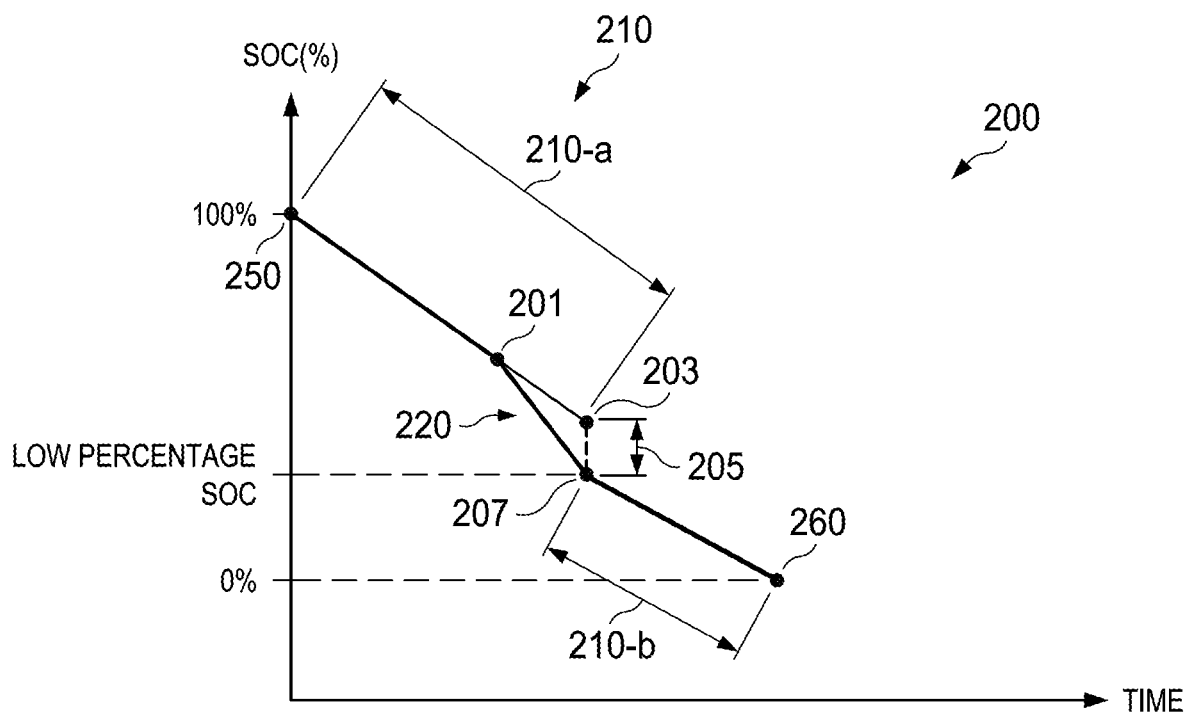


FIG. 2

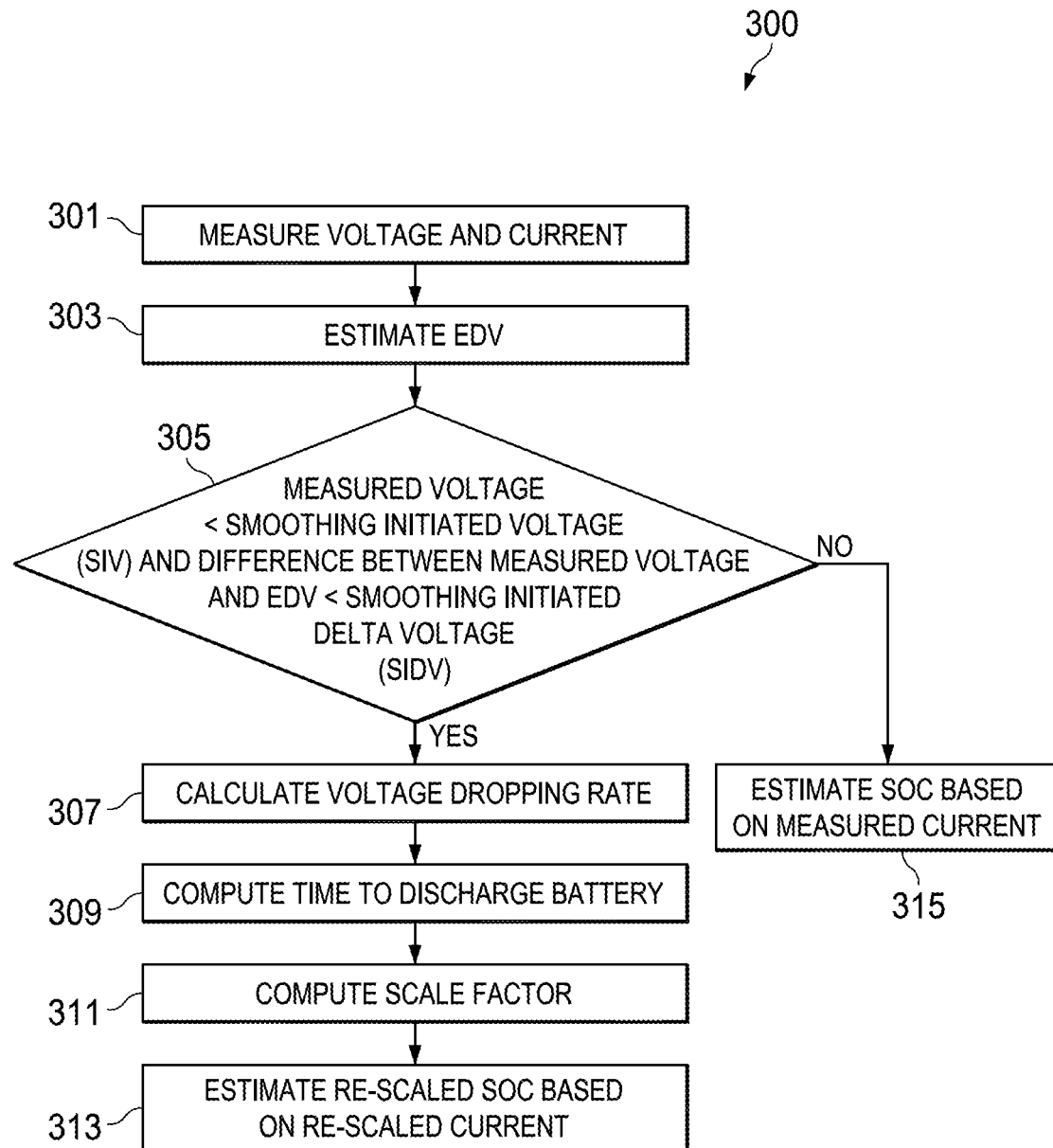


FIG. 3

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BATTERY CAPACITY MONITOR**CROSS-REFERENCE TO RELATED APPLICATION**

This is a continuation of U.S. Nonprovisional patent application Ser. No. 14/635,187, which is a continuation of International Application No. PCT/CN2014/089424, with an international filing date of Oct. 24, 2014, which are hereby fully incorporated herein by reference for all purposes.

BACKGROUND

Batteries are commonly used as power sources for portable electric devices, such as a mobile phones, laptop computers, tablets, etc. In general, a battery contains a limited capacity, which means that the battery is capable of supplying power for a limited amount of time before the battery needs to be recharged (in the case of rechargeable batteries). Battery monitors are used to monitor the remaining capacity of the battery in order to provide feedback to the operator of the battery-operated device as to how much useful battery life remains for the device.

SUMMARY

Systems and methods to monitor a battery's electric capacity by implementing a current rescale module are disclosed herein. In an embodiment, a method for dynamically monitoring a capacity of a battery includes estimating a first voltage threshold of the battery that is being discharged, wherein the first voltage threshold corresponds to a low capacity of the battery, and measuring a present voltage and a present current of the discharging battery. The method further includes re-scaling the present current based on the estimated first voltage threshold and the measured present voltage of the discharging battery, and calculating, based on re-scaling the measured present current, the battery's capacity before the present voltage level decreases below the first voltage threshold.

In another embodiment, an apparatus to determine a capacity of a battery includes a measurement unit to be coupled to the battery and configured to measure voltage and current levels of the battery at first periodic intervals and to save the measured voltage and current levels in a storage unit and a computing resource coupled to the measurement unit. More specifically, the computing resource is configured to estimate a first voltage threshold of the battery at each periodic interval, wherein the first voltage threshold corresponds to a low capacity of the battery, compare a present voltage level with a second voltage threshold, and compare a difference value between the present voltage level and the first voltage threshold with a third voltage threshold. If the present voltage level is less than the second voltage threshold and the difference value is less than the third voltage threshold, the computing resource is to calculate a voltage dropping rate of the battery. Further, the computing resource is configured to, based on the calculated voltage dropping rate of the battery, compute an amount of time to discharge the battery from the present voltage level to the first threshold voltage, based on the computed amount of time, compute a scale factor to re-scale a present current level, and estimate a re-scaled state of the battery's capacity based on the computed scale factor.

Yet in another embodiment, a method includes measuring voltage and current levels of the battery every second, estimating a first voltage threshold of the battery every

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second, wherein the first voltage threshold corresponds to a low capacity of the battery, and comparing a measured voltage level with a second voltage threshold, and a comparing a difference value between the measured voltage level and the first voltage threshold with a third voltage threshold. If both the measured voltage level is less than the second voltage threshold and the difference value is less than the third voltage threshold, the method includes calculating a voltage dropping rate of the battery based on previously measured voltages. Moreover, the method includes based on the voltage dropping rate of the battery, computing an amount of time to discharge the battery from the present voltage level to the first threshold voltage, and based on the computed amount of time, computing a scale factor to re-scale a measured current level so as to estimate a re-scaled state of the battery's capacity.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed description of exemplary embodiments of the invention, reference will now be made to the accompanying drawings in which:

FIG. 1 shows a block diagram to illustrate a battery monitor coupled to a battery in accordance with various embodiments;

FIG. 2 shows an example to compare state of charges (SOCs) calculated by two methods in accordance with various embodiments; and

FIG. 3 shows a flow chart to implement a current rescale module of a battery monitor in accordance with various embodiments.

NOTATION AND NOMENCLATURE

Certain terms are used throughout the following description and claims to refer to particular system components. As one skilled in the art will appreciate, companies may refer to a component by different names. This document does not intend to distinguish between components that differ in name but not function. In the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to" Also, the term "couple" or "couples" is intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection, or through an indirect connection via other devices and connections.

DETAILED DESCRIPTION

The following discussion is directed to various embodiments of the invention. Although one or more of these embodiments may be preferred, the embodiments disclosed should not be interpreted, or otherwise used, as limiting the scope of the disclosure, including the claims. In addition, one skilled in the art will understand that the following description has broad application, and the discussion of any embodiment is meant only to be exemplary of that embodiment, and not intended to intimate that the scope of the disclosure, including the claims, is limited to that embodiment.

In the use of battery-powered equipment, such as smartphones, electric vehicles, etc., it is desirable to monitor the battery in order to provide a prediction informing users of a

remaining capacity of the battery. In general, the remaining capacity prediction of a battery may be based on the state of charge for the battery.

The state of charge (SOC) for a battery is a characterization of the percentage of remaining energy, or capacity, available from the battery. The units of SOC may be percentage points (0% designating a fully drained battery; 100% designating a fully charged battery). Generally, SOC cannot be measured directly, but it can be estimated by measuring variables of the battery, such as current, voltage, and chemical values. More particularly, measuring the current flowing through the battery is also known as “Coulomb counting” (or “charge counting”). Coulomb counting involves calculating the SOC by measuring the battery current and integrating the measured current over time.

In addition to calculating the SOC based on the measured current, a battery monitor also may measure battery voltage and environmental conditions (e.g., ambient temperature) in which the battery operates and incorporates such measured variables (e.g., voltage and temperature) to further estimate the SOC. Generally, an algorithm is implemented in the battery monitor to use the measured variables for estimating the SOC. More specifically, a battery monitor periodically may measure voltage and current of the battery (e.g., once per second) during the battery’s discharge and, in real-time, may calculate one or more reference points (e.g., end of discharge voltage, also known as EDV) corresponding to a certain level of remaining capacity in the battery. That is, the EDV is a voltage that corresponds to the point at which a discharging battery has reached a lower threshold SOC point. For example, in addition to periodically measuring battery voltage and current, the battery monitor also may periodically re-calculate the EDV that is associated with a low percentage threshold of the SOC (e.g., 7%). The EDV voltage is a voltage at which proper operation of the battery-operated device can no longer be guaranteed. Generally, the EDV voltage threshold varies in accordance with various aspects of the operating battery, for example, a loading of the battery and ambient temperature around the battery. While the battery is discharging, the battery’s voltage may decrease and thus the SOC (i.e., battery’s capacity) decreases as well. As the measured voltage of the battery reaches the EDV level, the battery monitor may respond by, for example, alerting the user that the battery’s capacity has decreased to a level at which proper device operation can no longer be guaranteed. The SOC associated with the EDV point may be, for example, 7%.

However, in some battery monitors, the battery monitor may be subject to a discontinuous drop of the calculated SOC as the measured voltage reaches the EDV. In some embodiments, this discontinuous drop of the calculated SOC may be due to a lack of real-time updated full charge capacity (FCC) of the battery that may change with the battery’s loading and ambient temperature. The FCC of a battery may be measured in units of, for example, milliamp hours (mAh), and generally is the maximum value of how much energy a battery is able to discharge. The FCC of a given battery may vary with the battery’s loading, ambient temperature, the battery’s age, etc. For example, when the battery is coupled to a heavy loading (i.e., operable to drive a heavy load) and/or operates in a low ambient temperature environment, the FCC of the battery may be lower than in other conditions (lighter loading and/or higher temperatures), and the battery monitor may not update or be provided with an updated FCC value.

In accordance with the disclosed embodiments, a battery monitor is disclosed herein that automatically rescales the

measured current. By integrating the re-scaled current over time, an adjusted remaining capacity of the battery may be calculated by the disclosed battery monitor to estimate the SOC more accurately. As such, the disclosed battery monitor may avoid the discontinuous drop of the SOC. In other words, when the measured voltage of the discharging battery decreases to the EDV, the reported SOC (calculated via the re-scaled current) conforms to the referenced SOC (e.g., 7%) corresponding to the EDV. The disclosed embodiments to monitor the battery may be limited in electronic device, as well as other types of device that include a battery to be monitored.

FIG. 1 shows a block diagram of a system 100 to illustrate the disclosed battery monitor 106 in accordance with various embodiments. The system 100 includes a battery 104, a load 102, and a battery monitor 106. The load 102 coupled to the battery 104 may be a circuit (discrete circuit, integrated circuit, etc.) that performs any type of function or any other type of load. The battery monitor 106 is coupled to the battery 104. The battery monitor 106 may include a measurement unit 108, a computing resource 110, and a non-transitory, computer-readable storage device 112. The non-transitory, computer-readable storage device 112 may further include a current rescale module 114 which comprises machine instructions that are executable by the computing resource.

In some embodiments, the non-transitory, computer-readable storage device 112 may be implemented as volatile storage (e.g., random access memory), non-volatile storage (e.g., hard disk drive, optical storage, solid-state storage, etc.) or combinations of various types of volatile and/or non-volatile storage. The computing resource 110 is a hardware device and may include one or more processors, one or more computers, or any other type of computing resource to execute the current rescale module 114.

As a result of executing the current rescale module 114, the measurement unit 108 is to measure in real-time signal including the voltage and/or current of the battery 104 as well as other characteristics such as ambient temperature. Even though the battery monitor 106 as shown in FIG. 1 includes the computing resource 110, the storage device 112 and the measurement unit 108 as distinct components, in other embodiments, the computing resource 110, the storage device 112 and the measurement unit 108 may be part of the same component.

FIG. 2 shows a diagram 200 comparing two curves of SOC 210 and 220 estimated respectively by conventional and the disclosed battery monitor 106. That is, curve 210 is estimated by a conventional battery monitor and curve 220 results from the disclosed battery monitor 106. The diagram 200 includes an X-axis representing “time,” and a Y-axis representing SOC of a discharging battery (e.g., battery 104). In accordance with various embodiments, the unit of SOC (Y-axis) is % and the unit of time (X-axis) may be minutes. Continuing with the above example in which the battery discharges with heavy loading, the curve 210 of a conventional battery monitor illustrates the discrepancy between the reported SOC and the reference SOC. The curve 220 shows the SOC estimated by the disclosed battery monitor 106.

As shown in FIG. 2, the curve 210 of a conventional battery monitor includes a first segment 210-a, a discontinuous drop of SOC (identified at 205), and a second segment 210-b. More specifically, the first segment 210-a starts at point 250 and ends at point 203. The point 250 is generally referred to as 100% SOC, which means the battery is fully charged. The point 203, where the discontinuous

drop occurs, generally corresponds to the SOC at which the measured voltage of the battery reaches the EDV. The segment **210-b** starts at point **207** and ends at point **260** which corresponds to 0% SOC. The point **207** corresponds to an SOC percentage at the EDV point (e.g., 7%). The discontinuous drop occurs because the conventional battery monitor calculates the SOC based on a constant FCC. However, as discussed above, the FCC of a discharging battery changes with various factors including environmental parameters. Thus, when the measured voltage reaches the EDV, the actual SOC may be lower than the SOC calculated by the monitor. For example, at point **203**, the actual SOC may be at 7%, but the calculated SOC still shows a much higher value, such as 20%.

Referring still to FIG. 2, the curve **220** generated using the disclosed battery monitor **106** is a relatively smooth curve without the discontinuous drop of SOC at **205** characteristic of the SOC curve **210** resulting from some conventional battery monitors. More specifically, the curve **220** starts to decrease below the curve **210** at point **201**. In accordance with illustrative embodiments, the point **201** corresponds to a voltage threshold which is higher than the EDV of the battery. The voltage threshold may be a preset parameter defined in the current rescale module **114**. In accordance with current embodiments, the voltage threshold of point **201** is selected to avoid the discontinuous drop **205** before the voltage of the discharging battery decreases to the EDV since frequently, the discontinuous drop **205** occurs when the voltage approaches or reaches the EDV. From the points **250** to **201** in the curve **220**, the disclosed battery monitor may calculate the SOC by integrating the measured battery current.

Starting from the point **201**, the curve **220** of the disclosed battery monitor **106** diverges from the curve **210** of conventional battery monitors. While conventional battery monitors may continue to integrate the measured battery current, the disclosed battery monitor **106** re-scales the measured current and integrates the re-scaled current. The re-scaled current is based on estimating, by the disclosed battery monitor **106**, an amount of time that the battery needs to discharge from a present measured voltage to the EDV. Through estimating the amount of time, a more accurate remaining capacity (i.e., SOC) of the battery may be produced without the battery monitor updating the FCC that changes with the battery's loading and the ambient temperature. The re-scaled current may be computed by the current rescale module **114** upon execution by the computing resource **110**. Details of integrating the re-scaled current to produce the SOC (e.g., curve **220**) will be explained with respect to the flow chart in FIG. 3.

FIG. 3 shows a flow chart **300** to illustrate a method of implementing the disclosed battery monitor **106** in accordance with various embodiments. The operations shown in FIG. 3 may be performed in the order shown, or in a different order. Further, the operations may be performed sequentially, or two or more of the operations may be performed in parallel.

The method may be implemented as a result of the computing resource **110** of the battery monitor **106** executing the current rescale module **114**. The method starts with block **301** at which the measurement unit **108** of the battery monitor **106** measures the voltage and current of the discharging battery **104**. In block **301**, after the computing resource **110** executes the current rescale module **114**, the computing resource **110** may request the measurement unit **108** to start measuring voltages and currents of the battery **104** and retrieves the measured voltage and currents from the

measurement unit **108**. According to an illustrative embodiment, the measurement unit **108** may be configured to periodically measure the voltage and current (e.g., once per second).

The method continues at block **303** with periodically (e.g., once per second) estimating EDV of the battery **104**. As described above, the EDV of the battery may vary with the load **102** and/or the ambient temperature around the battery **104**. Thus, while periodically measuring the voltage and current of the discharging battery **104**, the battery monitor **106** also estimates the EDV in accordance with changing environment parameter, such as, a heavy or light load **104** and the ambient temperature.

Subsequently, the method continues at block **305** with, at a present time "t," comparing the voltage measured in block **301** with a smoothing initiated voltage (SIV), and comparing a difference value between the measured voltage (block **301**) and the EDV estimated in block **303** with a smoothing initiated delta voltage (SIDV). The SIV may be the voltage threshold corresponding to the point **201** in FIG. 2. In accordance with various embodiments, the SIV and SIDV may be preset and encoded in the current rescale module **114**. More specifically, the SIV may be desirable to be larger than a maximum value of the battery's EDV in order to prevent the discontinuous drop (e.g., **205**) of the SOC described with respect to the curve **210** in FIG. 2. Since the EDV varies with environmental parameters (e.g., temperature), a heavy loading and/or low ambient temperature may result in a low EDV. Thus, the SIV may be chosen to be larger than the maximum value of the battery's EDV.

As shown in FIG. 3, if the measured voltage (at time "t") is less than the SIV and the difference value (at time "t") is less than the SIDV, the method routes to block **307** at which a voltage dropping rate of the discharging battery **104** is calculated. A dropping rate is defined as a difference value between the maximum delta voltages of each of the previous two time intervals (e.g., one minute time intervals for this calculation). That is, the voltage dropping rate for the present time period is calculated based on data retrieved from the previous two time intervals. Assuming one minute time intervals and the voltage dropping rate for minute M is to be computed, data from minutes M-1 and M-2 are retrieved. The data retrieved from each of the prior two minutes includes the maximum delta voltage computed during each such minute. The delta voltage is the difference between the measured battery voltage and EDV. That difference may be computed once per second and thus there are 60 such delta voltages during each minute interval. The maximum delta voltage for a given minute is the largest of the calculated delta voltage values for that minute. Minute M-1 has a particular maximum delta voltage and similarly M-2 has its own maximum delta voltage. The difference between the maximum delta voltages from prior minutes M-1 and M-2 is the voltage dropping rate for the current minute M.

Referring still to FIG. 3, after the dropping rate is calculated in block **307**, the method advances to block **309** with computing an amount of time (T) to discharge the battery **104** from the present measured voltage (measured at **301**) to the EDV estimated at **303**. That is, a discharge time is computed from a present delta voltage to a zero delta voltage. In one example, the amount of time (T) is calculated by the battery monitor **106** as the present delta voltage divided by the dropping rate.

The method continues at block **311** with computing a scale factor to re-scale the measured current so that a re-scaled SOC may be obtained by integrating the re-scaled

current. In block 311, a delta remaining capacity of the battery 104 may be calculated by the battery monitor 106 as, $\Delta\text{SOC} \times \text{FCC} / 100\%$, wherein the ΔSOC is defined as a difference value between a present SOC and an SOC associated with the EDV. More specifically, the present SOC is calculated by the battery monitor 106 by integrating the present measured current (at time “t”), and the SOC associated with the EDV is the low percentage SOC as shown and described in FIG. 2. Generally, the SOC associated with the EDV is chosen as a low percentage value, such as 7%. After calculating the delta remaining capacity (ΔRM), an amount of current that is needed to discharge the battery from the present voltage to the EDV may be estimated by the battery monitor 106 as, $I = \Delta\text{RM} \times 60 / T$.

Still referring to block 311, a scale factor (β) is calculated based on the amount of current (I) and the present measured current. In accordance with various embodiments, the scale factor (β) is defined as, $I / \text{present measured current}$. As such, a re-scaled current at the present time “t” may be calculated by the battery monitor 106 as, $\beta \times \text{the present measured current}$.

Using the re-scaled current, the method continues at block 313 with estimating a re-scaled SOC. More particularly, the re-scaled SOC is calculated by integrating the re-scaled current over, for example, one second. As such, at each second after the measured voltage being determined to meet the conditions in block 305, the measured current will be re-scaled, and a re-scaled SOC will be estimated by the battery monitor 106.

Still referring to the flow chart 300, if the measured voltage (at the present time “t”) is not less than the SIV or the difference value (at the present time “t”) is not less than the SIDV, the method routes to block 315. In block 315, the battery monitor 106 estimates the SOC by integrating the present measured current (without first rescaling the current).

The above discussion is meant to be illustrative of the principles and various embodiments of the present invention. Numerous variations and modifications will become apparent to those skilled in the art once the above disclosure is fully appreciated. It is intended that the following claims be interpreted to embrace all such variations and modifications.

What is claimed is:

1. A battery monitor comprising:
 - a processor; and
 - a storage device coupled to the processor, the storage device storing instructions, which upon being implemented by the processor, cause the processor to:
 - retrieve a predetermined voltage threshold of a battery, the predetermined voltage threshold greater than an end of discharge voltage (EDV) of the battery;
 - receive a measured voltage and a measured current of the battery;
 - rescale the measured current to generate a rescale current based on a comparison between the measured voltage and the predetermined voltage threshold; and
 - estimate a state of charge (SOC) of the battery based on the rescale current.
2. The battery monitor of claim 1, wherein the processor is configured, via implementing the instructions, to generate an alert based on the SOC approaching an end of discharge capacity of the battery.
3. The battery monitor of claim 1, wherein the processor is configured, via implementing the instructions, to retrieve

the predetermined voltage threshold based on a loading of the battery and an ambient temperature of the battery.

4. The battery monitor of claim 1, wherein the processor is configured, via implementing the instructions, to estimate the SOC by integrating the rescale current over a predetermined time period.

5. The battery monitor of claim 1, wherein the processor is configured, via implementing the instructions, to rescale the measured current only when the measured voltage is less than the predetermined voltage threshold.

6. The battery monitor of claim 5, wherein the processor is configured, via implementing the instructions, to estimate the SOC of the battery based on the measured current when the measured voltage is greater than the predetermined voltage threshold.

7. The battery monitor of claim 1, wherein the processor is configured, via implementing the instructions, to:

- determine a voltage dropping rate of the battery before the measured voltage;
- determine a time to discharge the battery based on the voltage dropping rate;
- determine a scale factor based on the time to discharge; and
- apply the scale factor to rescale the measured current.

8. The battery monitor of claim 7, wherein the processor is configured, via implementing the instructions, to:

- integrate the measured current over the time to discharge to generate a first SOC;
- retrieve a second SOC associated with the EDV of the battery; and
- determine the scale factor based on a difference between the first SOC and the second SOC.

9. The battery monitor of claim 8, wherein the second SOC is 7% or less.

10. A tangible non-transitory computer storage medium storing instructions, which upon being implemented by a processor, cause the processor to:

- retrieve a predetermined voltage threshold of a battery, the predetermined voltage threshold greater than an end of discharge voltage (EDV) of the battery;
- receive a measured voltage and a measured current of the battery;
- rescale the measured current to generate a rescale current based on a comparison between the measured voltage and the predetermined voltage threshold; and
- estimate a state of charge (SOC) of the battery based on the rescale current.

11. The computer storage medium of claim 10, wherein the instructions, which upon being implemented by the processor, cause the processor to generate an alert based on the SOC approaching an end of discharge capacity of the battery.

12. The computer storage medium of claim 10, wherein the instructions, which upon being implemented by the processor, cause the processor to retrieve the predetermined voltage threshold based on a loading of the battery and an ambient temperature of the battery.

13. The computer storage medium of claim 10, wherein the instructions, which upon being implemented by the processor, cause the processor to estimate the SOC by integrating the rescale current over a predetermined time period.

14. The computer storage medium of claim 10, wherein the instructions, which upon being implemented by the processor, cause the processor to rescale the measured current only when the measured voltage is less than the predetermined voltage threshold.

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15. The computer storage medium of claim 14, wherein the instructions, which upon being implemented by the processor, cause the processor to estimate the SOC of the battery based on the measured current when the measured voltage is greater than the predetermined voltage threshold.

16. The computer storage medium of claim 10, wherein the instructions, which upon being implemented by the processor, cause the processor to:

determine a voltage dropping rate of the battery before the measured voltage;

determine a time to discharge the battery based on the voltage dropping rate;

determine a scale factor based on the time to discharge; and

apply the scale factor to rescale the measured current.

17. The computer storage medium of claim 16, wherein the instructions, which upon being implemented by the processor, cause the processor to:

integrate the measured current over the time to discharge to generate a first SOC;

retrieve a second SOC associated with the EDV of the battery; and

determine the scale factor based on a difference between the first SOC and the second SOC.

18. The computer storage medium of claim 17, wherein the second SOC is 7% or less.

19. A battery monitor system comprising:

a battery; and

a battery monitor device coupled to the battery, and configured to:

retrieve a predetermined voltage threshold of the battery, the predetermined voltage threshold greater than an end of discharge voltage (EDV) of the battery;

receive a measured voltage and a measured current of the battery;

rescale the measured current to generate a rescale current based on a comparison between the measured voltage and the predetermined voltage threshold; and estimate a state of charge (SOC) of the battery based on the rescale current.

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20. The battery monitor system of claim 19, wherein the battery monitor device is configured to generate an alert based on the SOC approaching an end of discharge capacity of the battery.

21. The battery monitor system of claim 19, wherein the battery monitor device is configured to retrieve the predetermined voltage threshold based on a loading of the battery and an ambient temperature of the battery.

22. The battery monitor system of claim 19, wherein the battery monitor device is configured to estimate the SOC by integrating the rescale current over a predetermined time period.

23. The battery monitor system of claim 19, wherein the battery monitor device is configured to rescale the measured current only when the measured voltage is less than the predetermined voltage threshold.

24. The battery monitor system of claim 23, wherein the battery monitor device is configured to estimate the SOC of the battery based on the measured current when the measured voltage is greater than the predetermined voltage threshold.

25. The battery monitor system of claim 19, wherein the battery monitor device is configured to:

determine a voltage dropping rate of the battery before the measured voltage;

determine a time to discharge the battery based on the voltage dropping rate;

determine a scale factor based on the time to discharge; and

apply the scale factor to rescale the measured current.

26. The battery monitor system of claim 25, wherein the battery monitor device is configured to:

integrate the measured current over the time to discharge to generate a first SOC;

retrieve a second SOC associated with the EDV of the battery; and

determine the scale factor based on a difference between the first SOC and the second SOC.

27. The battery monitor system of claim 26, wherein the second SOC is 7% or less.

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